Pointing Knowledge and Slew Rate Inputs to GLAST IRD

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1.0 Background

1.1 Slew definitions

We distinguish two different rates:

- Slew rate. This is an integral quantity describing an overall maneuver. A slew maneuver begins and ends at rest with respect to a target. The slew rate is the total angle through which the observatory rotates divided by the total time of the maneuver. The units used here are degrees/minute.
- Rotation rate. This is the magnitude of the instantaneous angular velocity. This quantity may also be called the angular speed, and has units of degrees/minute.

For a particular slew maneuver, the slew rate is the average rotation rate.

1.2 SRD

The SRD gives the following relevant specifications:

MISSION REQUIREMENTS:

- 40 arcmin accuracy
- <10 arcsec knowledge

These values are 1σ diameter.

- Rocking zenith pointing and steady target pointing observing modes.

MISSION GOALS:

- Targeting ability to point anywhere in the sky at any time
- More than one target per orbit
- Autonomous repointing in <5 minutes

1.2 Slew rate calculations

Although the requirements, in principle, should be defined independently of implementation, it is reasonable to check that the requirements result in practical component performance specs. Jennifer Bracken has supplied a spreadsheet that calculates the momentum wheel parameters (momentum capacity and reaction torque) given the three inputs of slew angle, slew time, and moment of inertia. A few things are worth noting about the spreadsheet calculation:

- The project has been using a moment of inertia of 3363 kg m^2. **This value should be reviewed for the new instrument baseline as soon as possible**, since all results depend directly on it. Lacking a careful review[1], we use this value here. It could be wrong by a significant amount, so our results should be considered preliminary.

- The slew calculation assumes a maneuver in which the bore sight comes to rest at the end of the allotted time period. A gentler torque or a faster response time is possible if we allow the instrument to be rotating relative to the target (though having a negative angular acceleration, coming to rest) when the source enters the FOV. We certainly want to be able to take data while the instrument is slewing. See the discussion about the star tracker and gyros below.
- The following table displays a sample of the results for different maneuvers:

angle[deg], time[min]	***90, 6***	***90, 7***	***70, 5***	***180, 12***
torque [Nm]	0.16	0.12	0.18	0.08
momentum capacity [Nms]	14.7	12.6	13.7	14.7

Notice that the torque requirement for a 180-degree slew in 12 minutes is more modest than for a 90 degree slew in 6 minutes.

These results are only preliminary. The numbers in the table, and the assumptions used in the spreadsheet, should be carefully checked.

1.3 Wheels

As a representative example, the relevant range of Ithaco reaction wheel capabilities is given in the following table:

Model	*TW-16**B**200*	*TW-19**B**300*	*TW-50**E**300*	*TW-26**E**300*
Torque[Nm]	>0.2	>0.3	>0.3	>0.3
Momentum capacity [Nms]	>16.6	>19.5	>50.0	>26.0
Peak power [W]	<250	<350	<280	<150
Mass (wheel+motor)[kg]	8.0	8.4	13.9	13.9

Typical costs for four wheels are $520k for the "**B**" wheels, and $1.2M for the "**E**" wheels. Note that the "**E**" wheels also have substantially lower peak power.

[1] Matt Fenske recently used the IMDC model, added a few missing masses (such as masses for the reaction wheels), and found the maximum moment of inertia to be 3623 kgm^2, or about 8% higher than the IMDC value.

2.0 Discussion

2.1 Slew rate

The statements in the SRD are somewhat indirect, and must be interpreted to derive the performance requirements. Both the rocking zenith pointed mode and the repointing requirements imply slewing.

Repointing
The worst-case repointing maneuver would be along the axis of a single wheel. The FWHM FOV of the instrument is approximately 55 degrees, and the earth horizon position does not change substantially in 5 minutes. Thus, the largest single slew angle is 180-2*55 = 70 degrees. The parameters for a 70 degree slew in 5 minutes are shown in the table.

All-sky Survey Rocking
The nominal zenith-pointed mode rock is from +45 degress to –45 degrees, or a 90 degree slew. The project has been carrying a slew time for this maneuver of 6 minutes, which should be reviewed. As it stands, the rocking requirement appears to be the main driver on the wheel selection. Relaxing this slightly to 6 ½ minutes would make the rocking and repointing requirements commensurate. Furthermore, an initial analysis by Seth Digel indicates that the optimal square rocking amplitude is more like 35 degrees (for 28 degree orbit inclination) to avoid over-exposing the poles.

Note that the nominal zenith-pointing maneuver of 360 degrees per ~90 minute orbit does *not* place significant demands on the reaction wheels, since this is primarily an inertial rotation.

Multiple Target Mode
The mission goal of more than one target per orbit implies two possibilities

A) a single target plus a scan when the target is occulted;
B) two individual targets on opposite sides of the earth.

The system requirements for option (A) are more modest, as the spacecraft can resume a gentle survey slew when the target is occulted. Option (B) again implies a ~70 degree slew as in the **Repointing** subsection above. In this case, time is again at a premium: Target 1 will be occulted for approximately 35 minutes. If the slew maneuvers to and from Target 2 last substantially more than 5 minutes each, observing of Target 2 will hardly be more efficient than in all-sky survey mode.

Summary on slewing discussion

The requirements on the reaction wheels from fast repointing, all-sky survey rocking, and multi-targeting are remarkably commensurate. These requirements do not place unusually large demands on the system, but accommodating them with adequate margin might result in using the higher-end “E” wheels. These wheels cost more money, but also use substantially less power. A compromise on the performance to save money would adversely affect all three goals of fast repointing, uniform daily sky coverage, and multi-targeting.

2.2 Pointing knowledge

The SRD clearly specifies a < 10 arc second pointing knowledge. There are two main components to the pointing knowledge error budget, each with their associated issues:

1. **Star tracker resolution**. The static resolution is fairly straightforward (and apparently easily met); however, we will want to take data while slewing and this imposes additional requirements. A standard star tracker model (*e.g.*, Ball CT-602) maintains its maximum resolution for rotation rates of <18 degrees/minute. At faster rates the tracker loses lock and resolution is significantly degraded. However, this relatively common state is readily handled by reverting to information from the gyros. The differential gyro information is actually far more precise than that from star trackers, provided the time intervals are not so long that the nominal gyro drifts begin to dominate. In typical systems (*e.g.*, using the Litton SIRU gyro), the pointing knowledge may be maintained to better than 2 arc seconds for star tracker outage periods of less than 15 minutes.

   Thus, for now, it seems reasonable to keep the same pointing knowledge requirement, while specifying the maximum rotation rate (30 degrees/minute for the above slewing maneuvers).
2. **Relative alignment of the star tracker and the instrument.** Since we are planning to calibrate this alignment on orbit, the alignment error requirement effectively becomes a set of requirements on stability:
   - alignment and stability on the ground
   - stability during launch (and environmental testing)
   - stability on orbit

3.0 Proposed Requirements

The information above is distilled into the following requirements:

Slew Rate

- The observatory maximum rotation rate during slew shall be 30 degrees/minute.
- The observatory shall be capable of repointing, autonomously or by ground command, by slewing as much as 70(TBR) degrees in less than 5 minutes, as specified in the SRD.
- To accommodate the rocking zenith pointed mode, the observatory shall slew 90 degrees (+45 degrees to/from –45 degrees) in less than 7(TBR) minutes, once per orbit, as specified in the SRD and MRD.

Pointing Accuracy and Knowledge

- The observatory shall be capable of pointing in any direction at any time, autonomously or by ground command, to an *accuracy* of <40 arc minutes [1σ diameter], as specified in the SRD.
- The *knowledge* of the observatory pointing direction at any time, including during slew, shall be such that the total error is < 10 arc seconds [1σ diameter]. This error budget includes
    - the intrinsic resolution of the star tracker and gyro system
    - the relative alignment of the star tracker system with the SI reference surface.

Mechanical Alignment and Stability

- The relative alignment of the star tracker system and the SI reference surface shall be surveyed on the ground and maintained to < 30(TBR) arc minutes [1σ diameter] during environmental testing and launch to orbit.
- The relative alignment of the star tracker system and the SI reference surface shall be calibrated once on orbit using celestial sources. Periodic alignment checkout observations shall be performed every TBD months.
- The stability of the relative alignment between the star tracker system and the SI reference surface, including all thermal-mechanical effects, shall be < 5 arc seconds [1σ diameter] throughout the mission.

[The pointing direction, pointing knowledge, pointing accuracy, and the SI reference surface should be explicitly defined.]